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A METHOD FOR MEASURING A GAS FLOW

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the priority of Swiss patent application 1015/99, filed May 31, 1999, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

The invention relates to a method for measuring a gas flow.

In a known method, gas flow is measured by guiding the gas over a sensor. The sensor comprises a membrane with a heater arranged thereon and extending substantially perpendicular to the gas flow. Temperature sensors are provided before and after the heater for measuring a temperature difference. This temperature difference depends on the gas flow and is converted to a corresponding measuring signal.

A disadvantage of such a method and device lies in the fact that the measuring signal depends strongly on the state of the membrane and in particular on contaminations of the membrane.

BRIEF SUMMARY OF THE INVENTION

Hence, it is a general object of the invention to provide a method of the type mentioned above that allows to obtain a measuring signal that shows less dependence on the state of the membrane.

Now, in order to implement these and still further objects of the invention, which will become more readily apparent as the description proceeds, the method for measuring a gas flow comprises the steps of leading the gas over a sensor, which sensor comprises a membrane with a heater and temperature sensors located thereon, measuring a first temperature difference before and after said heater, said first temperature difference depending in a first way from said gas flow and a thickness of said membrane, measuring a second temperature difference in addition to said first temperature difference, said second temperature difference depending in a second way from said gas flow and the thickness of said membrane, and combining said first and said second temperature differences for calculating a measuring signal depending less on the thickness of said membrane than said first and second temperature difference.

The invention is based, inter alia, on the understanding that the contaminations affect the thickness and thermal conductivity of the membrane, and that the measured temperature difference decreases upon increasing thickness and contamination of the membrane. To compensate this effect, at least one second temperature difference is measured that depends in a different manner from the membrane thickness and gas flow than the first temperature difference. By combining the two temperature differences, it is possible to generate a signal which exhibits smaller dependence on the thickness and contamination of the membrane.

Preferably, two further temperature differences are measured, preferably one before and one after the heater. These can then e.g. be added to generate a resulting signal that primarily depends on the thickness and contamination of the membrane. This sum can then be combined with the first temperature difference. Particularly good results can be ob-

tained from a division of the first temperature difference by a suited power of the sum.

In a particularly simple method, the first temperature difference is measured by means of two thermopiles, and the same thermopiles are also used for measuring the second and, where applicable, the third temperature difference.

The method according to the present invention is particularly suited for measuring gas flows in gas meters or similar devices.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings, wherein:

Fig. 1 is a first embodiment of a sensor for carrying out the method,

Fig. 2 shows the dependence of the first temperature difference from the gas flow for varying thickness (degree of contamination) of the membrane, wherein the contamination is simulated by increasingly thick layers of photoresist (A: no contamination, B: approx. 2 μm photoresist, C: approx. 3 μm, D: approx. 5 μm, E: approx. 8 μm),

Fig. 3 shows the dependence of a corrected value from the gas flow for varying thickness (degree of contamination) according to Fig. 2,

Fig. 4 shows the dependence of the first temperature difference from the gas flow for varying thickness (degree of contamination) of the membrane, wherein the contamination is simulated by increasingly thick layers of acrylic

resin varnish paint (A: no contamination, B: approx. 3 μm paint, C: approx. 6 μm, D: approx. 8 μm, E: approx. 10 μm), and

Fig. 6 a second embodiment of a sensor for carrying out the method of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a sensor as it has e.g. be described in detail in "Scaling of Thermal CMOS Gas Flow Microsensors: Experiment and Simulation", by F. Mayer et al., Proc. IEEE Micro Electro Mechanical Systems (IEEE 1996), pp 116 ff.

The sensor 1 is arranged on a single crystal silicon substrate 2, into which an opening or recess 3 has been etched. The opening or recess 3 is covered by a dielectric membrane 4. A resistive heater 5 is located on membrane 4. Two thermopiles 6, 7 used as temperature sensors are provided symmetrically before and after heater 5. The thermopiles 6, 7 and the heater 5 are arranged such in respect to the gas flow 8 that the gas first flows over first thermopile 6, then heater 5 and finally second thermopile 7. Furthermore, processing electronics (not shown), preferably in CMOS technology, are arranged on substrate 2 for processing the signal of the temperature sensors and converting the same into a measuring signal.

Each thermopile measures one temperature difference $\Delta T2$ and $\Delta T3$, respectively, between its contacts or rows of contacts 6a, 6b, 7a, 7b, respectively. Since the outer rows of contacts 6a, 7a are thermally connected over substrate 2, they are on the same temperature. Hence, the difference between $\Delta T2$ and $\Delta T3$ is equal to the temperature dif-

ference $\Delta T1$ between the two inner contact rows 6b and 7b before and after heater 5.

In operation of the device, a current is sent through heater 5. Depending on the application, heater 5 can e.g. be regulated to constant power, a given temperature, a given current or a given voltage. It is also possible to operate the heater in pulsed manner.

The first temperature difference $\Delta T1$ between contact tows 6b and 7b is a function of the gas flow F to be measured. It also depends on how much heat is carried off in membrane 4 from heater 5 the contacts 6b and 7a. Hence, it is a function of the effective thickness d of membrane 4. This effective thickness d is given by the actual thickness of membrane 4 itself and the thickness of the contamination layer covering membrane 4. In the following, the effective thickness is called the "thickness d" of the membrane.

Since the first temperature difference $\Delta T1$ depends not only from current F but also from thickness d, a contamination of the membrane leads to an error in the measuring result if the latter is derived from $\Delta T1$ directly. Hence, a correction is carried out in the method of the current invention, as it will be described in the following examples.

In a preferred embodiment, the temperature differences $\Delta T2$ and $\Delta T3$ are used for a correction because these two values also depend on the thickness d of membrane 4 as well as on the gas flow, but in different way than the first temperature difference $\Delta T1$. Hence, a signal S can be won by suited mathematical combination of the values $\Delta T1$, $\Delta T2$ and $\Delta T3$ that depends only weakly or not at all from the thickness d. It has been found that signal S is preferably derived by a function of the type

$$S = f(\Delta T1, \Delta T2 + \Delta T3) \qquad (1)$$

Hence, the sum of the temperature differences $\Delta T2$ and $\Delta T3$ is used for correcting the measurement. It has been found that the value $\Delta T2 + \Delta T3$ depends less on the gas flow F than the temperature differences $\Delta T2$ and $\Delta T3$ and is therefore better suited for correcting the temperature difference $\Delta T1$.

The correction function f preferably comprises a multiplication of suited powers of both arguments. In particular, the following correction is used:

$$S = f'(\Delta T1 \cdot (\Delta T2 + \Delta T3)^k)$$

Because the value of $\Delta T1$ as well as the one of $\Delta T2 + \Delta T3$ decrease with increasing membrane thickness, the exponent k is usually negative. It has been found that a value of $k = -5$ yields especially good results.

This is illustrated by the measured curves of Figs. 2 - 5. Figs. 2 and 4 show the value of the first temperature difference $\Delta T1$ in dependence of the gas flow for varying thickness or degree of contamination of the membrane. As it can be seen, the value of $\Delta T1$ decreases with increasing thickness d (or increasing degree of contamination). The measurements for Figs 2 and 3 were generated by applying increasingly thicker layers of photoresist on the membrane, those for Figs. 4 and 5 by applying increasingly thicker layers of an acrylic resin.

Figs. 3 and 5 show the corresponding curves for the value

$$\Delta T1 \;/\; (\Delta T2 + \Delta T3)^5.$$

As can be seen, this value depends only weakly on the contamination and is furthermore more linear in view of the gas flow.

Depending on geometry and design of the sensor, the ideal value for the exponent k can be different from 5. It is also possible that a correction according to equation

(2) is insufficient and that another formula of correction or suited correction tables must be used.

In the embodiment of Fig. 2, the thermopiles 6, 7 have been used for measuring all three temperature differences. It is, however, also possible to measure the second and, if required, the third temperature difference by means of one or more separate temperature sensors.

A corresponding embodiment of the sensor is shown in Fig. 6. Here, a further thermopile 10 is arranged at the edge of membrane 4. It measures the temperature difference between its contact points 10a and 10b. In this embodiment, it extends transversally to the direction of gas flow 8 over the edge 11 of membrane 4. The temperature difference $\Delta T2'$ measured by this thermopile is therefore substantially independent of gas flow F and results from the power of heater 5 and the thickness of the membrane and the corresponding temperature gradient in the membrane.

Similar to equation (2), the following correction can e.g. be used for this embodiment of the invention:

$$S = f''(\Delta T1 \cdot (\Delta T2')^k), \qquad (3)$$

again with $k < 0$.

In a preferred embodiment, the gas flow F is directly determined from the measuring signal S. It is, however, also possible to calculate the gas flow F in conventional manner from the first temperature difference $\Delta T1$ and a suited calibration function, while, however, the value obtained in this way is verified periodically in calibration measurements according to equation (1) and the calibration function is adjusted when necessary.

While there are shown and described presently preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto

but may be otherwise variously embodied and practised within the scope of the following claims.

CLAIMS

1. A method for measuring a gas flow comprising the steps of

leading the gas over a sensor, which sensor comprises a membrane with a heater and temperature sensors located thereon,

measuring a first temperature difference before and after said heater, said first temperature difference depending in a first way from said gas flow and a thickness of said membrane,

measuring a second temperature difference in addition to said first temperature difference, said second temperature difference depending in a second way from said gas flow and the thickness of said membrane, and

combining said first and said second temperature differences for calculating a measuring signal depending less on the thickness of said membrane than said first and second temperature difference.

2. The method of step 1 further comprising the step of measuring a third temperature difference in addition to said first and second temperature differences.

3. The method of step 2, wherein said second temperature difference is measured before said heater and said third temperature difference is measured after said heater.

4. The method of claim 2, comprising the step of calculating or checking said measuring signal by combining said first temperature difference with a sum of said second and said third temperature differences according to

$$S = f(\Delta T1,\ \Delta T2+\Delta T3),$$

wherein S is said measuring signal, $\Delta T1$ is said first temperature difference, $\Delta T2$ is said second temperature difference, and $\Delta T3$ is said third temperature difference.

5. The method of claim 4, wherein said measuring signal calculated or checked according to

$$S = f'(\Delta T1 \cdot (\Delta T2 + \Delta T3)^k)$$

with an exponent k.

6. The method of claim 5, wherein said exponent k is approximately equal to -5.

7. The method of claim 1, wherein said first temperature difference is measured by means of two thermopiles, wherein each thermopile has a first and a second contact row, wherein said first contact rows are arranged on said membrane at different temperatures before and after said heater and wherein said second contact rows are arranged at equal temperatures, and wherein said second temperature difference is measured over one of said thermopiles.

8. The method of claim 7, wherein said membrane extends over an opening in a semiconductor substrate, wherein said second contact rows are arranged on said semiconductor substrate.

9. The method of claim 1, wherein said membrane extends over an opening in a semiconductor substrate and said measuring signal is calculated by measuring electronics arranged on said semiconductor substrate.

10. The method of claim 1, wherein said heater is operated by keeping a parameter selected from the following group constant: electric power, temperature, voltage and electric current.

11. The method of claim 1, wherein said heater is operated with a pulsed current.

12. The method of claim 1, wherein at least three temperature sensors are arranged on said membrane, wherein said first temperature difference is measured by at least a first and a second of said temperature sensors and said sec-

ond temperature difference is measured by at least a third of said temperature sensors.

13. The method of claim 1, wherein said second temperature difference over said membrane.

14. The method of claim 13, wherein said second temperature difference depends on a temperature gradient in said membrane in a direction prependicular to said gas flow.

ABSTRACT OF THE DISCLOSURE

For measuring a gas flow, a gas is led over a sensor. The sensor comprises a thin membrane with a heater and temperature sensors arranged thereon. Three temperature differences are measured by means of the temperature sensors and combined for generating a measuring signal. This measuring signal exhibits substantially no dependence on the thickness of the membrane and therefore no dependence on a contamination of the membrane.